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THE GAP BETWEEN ACTIVE AND PASSIVE SOLAR HEATING*

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ABSTRACT

The gap between active and passive solar could hardly be wider. The reasons for this are discussed and advantages to narrowing the gap are analyzed. Ten years of experience in both active and passive systems are reviewed, including costs, frequent problems, performance prediction, performance modeling, monitoring, and cooling concerns. Trends are analyzed, both for solar space heating and for service water heating. A tendency for the active and passive technologies to be converging is observed. Several recommendations for narrowing the gap are presented.

INTRODUCTION

Active and passive solar heating approaches have tended to evolve separately, driven by different issues, developed by different groups of people with different outlooks. This separation has been detrimental to both technologies because each could benefit from a good understanding of the other. Recent developments in the construction of buildings, namely the trend toward much higher levels of conservation and toward increased use of natural lighting are very important to the future of both active and passive solar, tending to favor solar energy systems that combine both active and passive features. Hence, the gap should be narrowed. The purpose of this paper is to explore the differences, to assess the weaknesses and the advantages of each approach, to analyze the trends, and to draw conclusions as to appropriate directions. We certainly do not wish to further widen the gap but through an honest discussion to help bring the different camps together.

TEN YEARS OF EXPERIENCE IN SOLAR SPACE CONDITIONING

Although major development of active systems preceded that of passive systems by about 2 years, each has seen about 1 decade of vigorous experimentation, demonstration, evaluation, and evolution. Many problems have been discovered and solved, often repeatedly by different groups in different places. But the issues and problems of active and passive systems have tended to be very different. Table I lists the key items. The major issues and problems for active tend to be minor ones for passive and vice-versa. Often advocates of one technology have not been complimentary to the other, exploiting and exaggerating weaknesses.

The technologies separated. Conferences tended to become specialized, those emphasizing active system approaches were attended mainly by engineers concerning themselves with mechanical issues and packaged systems; those emphasizing passive systems gravitated toward architectural and builder interests. Although both groups tended to learn from their mistakes, they solved their problems separately.

The building of a solar industry became the primary concern of those working with active systems. Their emphasis has been on manufacturing and testing components. Only lip service was given to improving the characteristics of the building. That was considered as a fixed load. Indeed, many argued that an advantage of active is that the building form need not be altered and that the building occupant can go on oblivious to the presence of the system.

Meanwhile, passive advocates relished the architectural differences and tended to emphasize design issues. We saw many extreme solar designs featuring entire south facades of glass. Component development was restricted primarily to movable night insulation devices and specialized heat storage elements. The competition between conservation and passive solar strategies was evaluated and much discussed. Although active elements were frequently added to a passive building, such as a fan-forced rock bed or heat distribution system, these were often poorly designed and were almost never evaluated.

TABLE I

PROBLEMS AND ISSUES

		Active	Passive
Frequent Problems:	Poor reliability:		
	Corrosion	M	-
	controls	M	m
	freeze damage	M	-
	Poor design	m	M
	Poor performance	m	m
	Improper installation	M	m
	Discomfort	m	M
	High cost	M	m
Main Issues:	Marketing	M	m
	Architectural integration	m	M
	Aesthetics	m	M
	Installation procedures	M	-
	Improved reliability	M	m
	Increased performance	M	m
	Packaged systems	M	m
	Standard test procedures	M	m
	Monitoring whole-system performance	M	M
	Integration with DHW	M	-

M = Major, m = minor.

*Work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

Costs

Although the costs of active systems were expected to decrease with increased production volume, this never really happened. Manufacturing costs did decrease, but these were more than offset by the increased cost of distribution. This was then compounded by the increased cost of marketing expensive systems. Costs have skyrocketed, and many US manufacturers and distributors maintain that a solar industry cannot be maintained without tax credits. Active system costs in North America have generally been within the range of $500 to $1000 per m^2 of solar collector area, although many installations both above and below this range can be found.

Passive system costs proved to be difficult to separate from the building itself because passive system designers realized the cost advantages of making multiple use of building elements. The main problem this caused was to frustrate the economists; the designers paid little attention to the issue because passive system costs could easily be absorbed into the building cost. Nonetheless, some incremental passive system costs have been identified. The range is from $50/m^2$ of glazing for simply increasing the size of a south window to as much as $400/m^2$ of glazing area for a sunspace, but these are both misleading. The cost of direct gain should properly include the cost of necessary added mass if the building intrinsic mass is not sufficient; this might increase the cost by an additional $50/m^2$ or $100/m^2$ of glazing. For a sunspace, generally at least 2/3 of the cost can usually be charged off against the aesthetic and functional value of the room. Accounting for these effects results in passive system costs of $100 to $200/m^2$ of glazing, making them much more cost effective than most active space heating systems.

Frequent Problems

Other than high cost, the key problems of active systems have been poor reliability, improper installation, faulty components, and inadequate maintenance. Many of the initial installations experienced all of these. Problems with controllers and pumps have been particularly notable and damage due to corrosion and freezing have been frequent. Slowly, most of these problems have been cured and contemporary installations are usually based on tested and proven components in tested and proven designs. Diligence is required to achieve a trouble-free system. Packaging systems has proven to be the best approach to improving reliability.

Passive systems have other problems. Many buildings are poorly designed and do not work well. This is caused partly by the apparent simplicity of passive design principles and a lack of understanding of the important subtleties of good design. A key problem has been the tendency for many designers to rely entirely on direct gain in buildings with insufficient or poorly placed thermal mass for heat storage. The result is discomfort due to large temperature swings. Other common design errors are sunspaces with inadequate summer sun protection and Trombe walls with excessive heat leaks to the outside. Passive designers have generally been slower than active designers to recognize their problems and to correct them.

Concern over summer overheating has been a major issue for passive solar. It is important to note that this concern has been a red flag raised more by speculative fears and computer simulation than by any demonstrated problem experienced in the field or from monitored building results. Most conventional (nonsolar) buildings are very badly designed for summer comfort. Passive buildings, however, have been designed with a much greater consciousness of climatic factors and have thus avoided many of the key pitfalls, such as exposed west windows, and have almost invariably worked better in the summer than their contemporary counterparts. Even so, it is still true that passive heating elements can exacerbate summer cooling loads, and designers in climates with hot summers should be cognizant of the issue and design conservatively.

Performance Prediction

Technical work on both active and passive systems has focused primarily on performance prediction with an emphasis on estimating annual energy savings. Unfortunately, thermal comfort has been much less analyzed. Many of the same scientists have worked on both passive and active evaluations and, thus, there is some commonality between the results. Hour-by-hour simulation analysis has been the backbone of these evaluations and the degree of confidence in the accuracy of the calculations has been high. The mathematical models have been validated primarily by comparison of predictions with the results from component tests and test rooms. Correlation methods, which use results from simulations, have been developed and are widely used by designers, primarily the F-chart method for active systems and the Solar Load Ratio method for passive systems. These are amenable to hand analysis but are often implemented on a microcomputer. Calculations are done monthly, but, with some loss in generality, the results can be tabulated in easier-to-use annual performance tables for a particular locality.

Performance Monitoring

Large-scale programs have been undertaken to monitor and report the performance of groups of both active and passive buildings. Many other individual buildings have also been monitored. The results have been quite valuable in providing important feedback to designers and confirming the good performance of correctly designed systems. Early active system installations were shown to be rife with design and installation errors. Passive systems tended to be more forgiving, partly because the building trades were more familiar with the design elements, but the good performance achieved could sometimes be traced more to good conservation practice than to passive solar design.

Cooling

The idea of using solar energy for space cooling has been very popular, in part due to high solar availability just at times of greatest cooling load. A great flurry of activity was devoted in the late 1970s to developing active space cooling systems. These generally have been closed-cycle designs using a chemical heat pump, such as a LiBr chiller, or a mechanical heat pump, such as a Rankine cycle engine driving a vapor compression chiller. The general experience with those systems has been extremely disappointing. They are very complex and expensive and the performance has usually been poor. One important measure of efficiency is the electrical coefficient of performance (COP), which is the ratio of cooling energy delivered by the system to the heat equivalent of the electricity consumed by the system. For many of the designs, this COP has been in the range of 0.5 to 3 and for the better designs it has been in the range of 4 to 7. By comparison, the electrical COP of a conventional electric-driven vapor compression chiller is about 3 and advanced designs could achieve 4. It may well be that closed cycle active solar cooling is a dead-end technology, although a few advocates contend that through good design, performance could be increased to a COP of 10 and costs reduced to be competitive.

Open cycle active solar cooling may offer more promise. These usually use a desiccant, such as LiCl or silica gel, which is concentrated using solar heat in direct contact with the atmosphere. There is a variety of designs, some of which have achieved an electrical COP greater than 15. Development continues at a slow rate due to a general disillusionment with active solar cooling.

Passive cooling is not a solar technology in the strict sense; however, its evaluation and implementation have been achieved primarily by researchers and designers concerned with passive solar space heating. The most important factor is avoidance of solar cooling loads by keeping the sun out of the building when cooling is required. The methods of removing heat passively are natural ventilation, radiation to the sky, coupling to cool earth, and evaporation. Ventilation and evaporation are often hybrid (or active) approaches in that a fan is used to achieve the desired levels of air motion. With the exception of evaporative coolers, these techniques have lacked, and still lack, a solid analytical basis, although they are all demonstrably effective under suitable climatic conditions.

SOLAR SPACE HEATING--TRENDS AND IMPLICATIONS

Better Buildings

By far the most important trend for both active and passive solar space heating is not directly related to either. It is the trend toward buildings with very much higher levels of conservation. Beginning in the Canadian plains and also in Scandinavia and then spreading into the colder regions of the US, these buildings have come to be known as superinsulated. The key features are high levels of insulation in walls, ceiling, and perimeter, and nearly airtight construction of the exterior envelope. Typical values are RSI-7 wall insulation ($U = 0.14\ W/m^2\ C$ or $0.025\ Btu/ft^2\ h\ °F$) and natural infiltration rates of less than 0.1 air change per hour. Indoor air quality is maintained by controlled ventilation of at least 0.6 air exchanges per hour, usually using heat recovery from exhaust air.

The energy performance results from these buildings have been impressive, confirmed by the monitoring of many houses. Typical building total heat loss coefficients are in the range of 0.7 to 1.2 W/°C per m^2 of floor area (3 to 5 Btu/°F-day per ft^2 of floor area). In a building with heat losses this low, the internal heat from people, appliances, machinery, and lights provides a significant portion of the building heat, often reducing the energy needed for heating a residence by as much as 1/3. The internal heat raises the inside temperature by about 6°C. The effect is to shorten the heating season and to reduce the integral of heat needed. This reduces the operating time and the cost effectiveness of any solar space heating strategy, either active or passive; however, it does increase the fraction of the load that is satisfied by solar.

Another important effect of superinsulation is to reduce the peak heating required and thus reduce both the size and cost of the back-up heater. A typical size for a 110 m^2 building with a 40°C design ΔT would be 4.4 kW compared with heating plant in a contemporary house of 25 kW. This has profound effects on our normal thinking about the nature of the back-up heater. The need for distribution of heat to every room may be reduced. For example, natural convection through an ordinary doorway will provide sufficient heat distribution for an 8 m^2 room, assuming a 2°C temperature difference between rooms. Of course, the door must be open most of the time for this to be effective. It becomes feasible in many cases to rely on natural convection for the bulk of the heat distribution and to rely on small electric zone heaters for fine-tuning comfort control. Back-up heat can be released at only two or three carefully chosen places in the building, greatly reducing the installed cost of the system.

Another important related trend is windows with lower heat loss characteristics, often called superglazings. Heat loss coefficients (U-value) in the range of 1.4 to 1.8 W/°C m^2 are achieved through the use of special coatings applied either to the glass or to plastic films suspended between double glass layers. Two types of coatings have been used commercially, low-emittance coatings and high-transmittance coatings. The former are used to greatly reduce heat transmission by infrared radiation. The latter are used to build up multiple glazings (usually four) without unduly increasing weight and cost or unduly decreasing solar transmittance. The reduction in transmittance of low-emittance coatings is significant in some cases, offsetting the benefit of reduced heat loss in passive solar applications. An important benefit of these superglazings is to increase the inside surface temperature of the window and to therefore greatly improve the thermal comfort of the building and also to reduce the tendency for water vapor to condense on the window surface.

These observations bring up two important questions: how far will the superinsulation trend extend, and, how will it effect solar energy design? We expect the trend to continue and to extend to warmer climates. This is already happening. It may also extend to commercial buildings, although the design issues are quite different. If the objective is to design buildings with good thermal integrity, then solar must fit into the scenario of buildings with much better conservation levels. One reason is that this is the most cost effective approach; the many studies that have been done show that the economic optimum balance between passive solar and conservation leads to high conservation levels, especially in cold climates or in cloudy climates, and to superinsulation values in climates that are both cold and cloudy.

One effect of better buildings is that solar systems, like back-up heaters, should become smaller. This is a major benefit in that it reduces cost and increases architectural freedom. Also solar energy distribution can be more localized. The solar system can, but does not necessarily need to be integrated with the back-up system.

Commercial Building Issues

The energy issues of commercial buildings are usually very different than for residences. Energy used for lighting is often 1/3 of the total and another 1/3 may be needed for cooling, in no small part due to the internal heat generated by the lights. The energy used for heating is usually a smaller fraction of the total, except in the most severe cold climates. An important solar application is the use of solar radiation for daylighting, and there is a rapidly increasing emphasis on the use of this technology, although it is quite far afield from what most solar technologists have considered as solar energy. The most direct energy effect of daylighting is to reduce the electrical energy used for lights. The timing is good because most commercial buildings are primarily for daytime use. However, it is well established that most building occupants will not turn off artificial lights even if daylight is available and, thus, energy can only be saved if there is an automatic control system to balance artificial light with available daylight. It is also well established that cooling energy can also be saved by use of daylight because it is more efficient (less heat for the same amount of light) than fluorescent lights, which are themselves much more efficient than incandescent lights. However, the design must be very carefully integrated or the potential energy benefits will not be realized, in fact, a poorly executed daylit building may use more energy.

In the US, electricity charges for commercial buildings are usually based on peak demand in addition to total consumption. Daylighting can be used to greatly reduce peak demands, which most often occur in sunny, hot weather when daylight is most available.

The whole set of energy issues relating to commercial buildings is very complex and depends on many factors, including building type, occupancy patterns, location, and aesthetics. No clear design process that leads to the best building has yet evolved, however, as in residential buildings, there are many examples in many climates that have demonstrated energy use requirements of only 10 to 25% of contemporary buildings. Extra costs for the energy saving features are usually offset by reductions in the installed cost of the heating, ventilating, and air-conditioning equipment.

A popular design feature for commercial buildings is the use of an atrium. The atrium is strongly daylit, and this light source can be used in the spaces adjacent to the atrium; the heat can also be used when needed. As in all passive solar designs, the design must achieve an appropriate phasing of the availability of solar energy and its need in the building. Thus, it is no coincidence that passive solar designers have been on the forefront of the trend toward more efficient commercial buildings.

Hybrid Systems

There is a trend toward designs that are not purely active solar or passive solar. One example is an active collection and storage system with passive discharge, such as an air heating collector with fan-forced flow through hollow core concrete, concrete block, or brick floors, walls, or ceiling elements of the building. Heat distribution is uncontrolled; the warmed surfaces simply radiate and convect to the building. Temperature swings must be kept small, but the efficiency can be quite high because the collector is operated only slightly above the comfort zone temperature. Comparable systems using water as the distribution fluid have also been built.

Another example is a design that is largely passive solar but with some active distribution, such as the common practice of using a fan to assist distribution of heat to the building, perhaps using the same type heat storage in hollow-core building elements mentioned above.

The experience with these hybrid approaches has been mixed. Many have been properly designed and have worked well; others have either worked poorly or have caused discomfort, often because the heat storage mass is inadequate and is too closely coupled to the building.

SOLAR WATER HEATING: TRENDS AND IMPLICATIONS

Service water heaters, either for domestic hot water in residences or for central systems used in applications such as hotels, laundries, or car washes, are a special case and deserve special attention. These represent by far the largest number of solar heating applications worldwide and are the basis of the solar industry in most countries.

There are perhaps as many as 5,000,000 solar water heaters in use today. Most of these would be classified (at least by some) as passive systems in that there is no external energy required for their operation, that is, no pumps or controls. There are about equal numbers of thermosiphon and integral (batch) systems, with thermosiphon types gaining in popularity because of their superior performance. In many countries with mild climates, the systems have no overt method of freeze protection, but the trend is definitely toward systems with protection against mild freezing, and, in some designs, very severe freezing conditions.

There are strong solar water heater industries in many countries, most notably in Japan, Israel, Greece, Cyprus, South Africa, Australia, and Canada. In most cases the installed cost of a system of 2-4 m^2 collector area will be between $800 and $1500.

The US has taken a very different pattern of development. Nearly all the installations in the 1970s were active systems with the tank located in the house and the collectors on the roof. Many approaches have been developed, the most prevalent being drain-back and drain-down systems, using water in the collectors, and two fluid systems, most often using glycol/water as the second fluid. Heat exchange to the potable water tank is either through a coil in the tank or through a heat exchanger external to the tank. After many initial problems, the industry has established a firm base, manufacturing and distributing a variety of systems in which all components except the collector are packaged together. The cost of a system in the US, with a collector area of 4-8 m^2, will be in the range of $3000 to $8000. Much of this cost is associated with the extensive marketing techniques used. Tax credits offset 40-90% of this cost, depending on the particular state where the system is installed.

More recently, there has been a strong trend toward development of passive thermosiphon and batch heaters in the US and many brands are now marketed. The performance of the thermosiphon systems is comparable to good active systems. Many of the batch heaters also perform quite well due to extreme isolation from the environment by means of thick insulation, multiple glazings, and selective surface coatings on the tank. Most systems are advertised as pre-heaters for a conventional hot water tank located within the house.

Freeze protection is almost always a major issue in water heaters, not only in the collector, but for all piping and fittings exposed to outside temperature conditions.

Freon Systems

One trend warrants particular note: systems that use Freon as the working fluid. The fluid is boiled in the collector and condensed within tubes located in the water tank, resulting in heat transfer at very low temperature differences, which leads to improved system efficiency. Moreover, Freon has other desirable properties: it is not corrosive, does not cause freeze damage, and does not result in extreme pressures at high temperatures.

As with other water heaters, there are two principal configurations of Freon systems. The first operates in a passive mode: the water tank is placed above the collector, heat transfer is by a gravity-assisted heat pipe action in which the Freon liquid boils in the collector tubes, the vapor rises in this tube and condenses in the upper portion in thermal contact with the water in the tank, and the condensate then flows back to the collector by gravity. One manufacturer employs Freon-22, which has a critical temperature at 95°C. This is an effective safety measure because heat transfer stops at 95°C and thus the water in the tank cannot be heated above boiling. The collector in this particular case is an evacuated tube capable of very high temperatures and thus the precaution is particularly appropriate.

The second type of system that has evolved is an active system using a small pump to raise the condensate into the collector, thus enabling it to be placed at any height above the water tank. The pump need not operate continuously if a small reservoir is placed above the collector; the parasitic power required is extremely small. Very high daily efficiencies have been obtained, in excess of 60%, because the collector is operated at the coolest possible temperature, being always flooded with liquid.

There is a third category of Freon-based systems that is now under development. These are self-pumping designs, that is, systems in which the collector can be placed above the water tank. The pressure created by boiling Freon raises the condensate to the collector. One type operates continuously using a bubble pump action or a geyser action to lift the liquid; however, the lift that has been achieved is only about 1 meter. This type may be suitable when the collector and the tank are at about the same level. The second type of system operates cyclically, usually with a cycle time of 1 or 2 minutes. During one part of the cycle the pressure of the boiling Freon forces the condensate upwards into a reservoir above the collector. A valve is then opened that allows the liquid in the reservoir to drain into the collector. The valve is then closed and the cycle repeats. Designs of this type have been patented in Italy, Israel, Argentina, and the US. The valve can be automatic, using a float valve principle, and thus no external energy is required for operation. The system is potentially very reliable, quite efficient, and can operate with a height difference between collector and tank of many meters, although efficiency does decrease as the height difference increases.

ANALYZING THE GAP

The message that emerges from the foregoing discussion is that the gap between active and passive solar is becoming less distinct, at least in terms of the technologies themselves. In many cases it is even ambiguous whether a system should be classified as active or passive. A case in point would be the self-pumping Freon water heating systems just described. One could claim that they are passive because there is no outside energy required and their operation is automatic. However, they are certainly mechanical in nature and are built with traditional active system components by active solar practitioners. The distinction between active and passive is not important in this example, and it is fruitless and distracting to pursue it. These systems will not succeed or fail based on our classification scheme.

Unfortunately, even though the technologies of active and passive solar may be converging, this does not mean that the gap between the practitioners of these two technologies is getting narrower. There are true philosophical differences of approach that separate these groups. It is not quite so simple as to say that active practitioners are often engineers and that passive practitioners are often architects, but this tendency is clearly present. Nor is it as simple as to say that active system designers tend to complicate designs, add unnecessary mechanical components and controls, and analyze the performance in exquisite detail while passive solar designers tend to oversimplify, are generally ignorant of the characteristics of mechanical systems, and ignore quantitative analysis, although these tendencies also exist. Perhaps the most telling observation is that passive designers tend to rely on natural processes and maximize the integration of the system into the building architecture, while active designers tend to mistrust natural processes and maximize the integration of their equipment into the building mechanical plant.

Each group has much to gain from a better understanding and a closer cooperation with the other. Each approach has distinct advantages and through a blending of the best characteristics, better systems and better designs can result.

Blending the Best Features

The key strengths of active solar design are flexibility in integration into the building, reduction of heat losses, and controllability. The key strengths of passive are high cost effectiveness, reliable operation, and simplicity. Improved new system designs will combine these attributes.

The next step is to systematically analyze the reasons why frequent problems for one approach are minor problems for the other. Here it is useful to refer back to Table I, where these are listed. We will follow the same order in the following discussion.

Poor Reliability. This has been a problem for active because of higher temperatures, use of incompatible materials, and complex design. Reliability has not been a major problem for passive because most of the elements used are more familiar to the building trades, the problem areas have long since been worked out, and because the operation is simpler. Here the active designers may profit by using lower temperatures, simplifying the design to the barest essentials, and choosing components that are nearly fail-safe, readily available, and for which failures are easily detected. Often passive components can be substituted for active components, for example, a float valve can be used instead of a solenoid valve, or natural convection flow through a heat exchanger might be used instead of forced convection. Reliability takes time and experience to work out. This has already happened to a great extent, and the problem is diminishing.

Poor Design. This has been a problem for passive because inadequate attention is often paid to correct sizing of solar collection and heat storage and to analyzing how the system will respond under all possible conditions. By contrast, active system designers have been much more conscientious in their analysis and the design is more repetitive; therefore, once the design problems are solved, the system can be replicated. Passive design, however, is seldom replicated exactly because the architecture of each building is usually different. Even so, the passive designer can learn much from active designers, particularly in two areas.

The first area is in the design and installation of active elements in predominantly passive designs, for example, a fan-forced heat storage system. Typically these are not well done by passive designers who tend to assume that a device will work and don't clearly identify all the steps required to achieve success. The use of the particular device will often differ in some significant degree from the normal use intended by equipment suppliers and installers who may not even be apprised of its new intended function. Active system designers are usually quite familiar with these issues and tend to be more accomplished in seeing to their proper execution.

The second area of assistance is in analysis. Many passive and passive-hybrid systems are not adequately evaluated prior to construction. The frequent result is inappropriate system sizing and far-from-optimum choice of system elements. It is especially true for mixed designs, such as a mix of Trombe wall and direct gain, that the passive design could benefit from a thorough evaluation. Simulation analysis is quite effective for studying these interactions and also for studying the interaction between the solar systems and the building controls. But simulation is a specialized technical subject involving sophisticated computer codes with complex inputs, more amenable to engineers and scientists than to the typical building designer. A key problem is that analysis does not fit comfortably into the design process. It is too laborious and slow, too numerical and not sufficiently graphic. The time between asking the question and obtaining an answer is too long. When the answer is obtained, it is usually not easy to relate it to better design decisions.

Poor Performance. As indicated, this has been a minor problem for both active and passive, but for different reasons. With active systems the problem most often develops because the system controls do not operate as intended, an indication that the design evaluation has not been sufficiently thorough. With passive, the problem is usually excessive heat leaks or the use of an inappropriate system for the climate. The solution for both groups is to do more analysis ahead of time and to carefully monitor and understand the performance of at least one installation. The solutions will usually be fairly obvious.

Another important consideration is to design solar energy systems that fit well into the situation in which they are to be used. The failure to do this explains why some active systems and some passive systems have not been well accepted by residential occupants. The active systems are too complex and require the owner to understand the system in order to assure proper operation and maintenance. The passive systems had a different problem. They required the house occupant to make many adjustments, for example, the operation of night insulation or vents. In both cases the system usually fails to operate properly because the designer has imposed upon the building occupants beyond their capability or willingness to cooperate. The same conclusions have been reached in the monitoring of daylighting schemes that rely on user cooperation.

Improper Installation and Operation. This has been a major problem for active due to a failure to understand the necessity for designing systems that can be correctly installed by normal building trades without an unreasonable level of training. The solution too often has been to bypass the conventional building trades and train specialists. This increases costs and greatly reduces wide-scale acceptance. Passive designers use more conventional components and where problems have arisen, it is usually because of a departure from this practice. The solution is to use components that are either fully understood, are fully packaged so that the installation is straightforward, or have very standardized design details. For this reason packaged thermosiphon water heaters have had less installation problems than distributed systems, and Trombe walls without thermocirculation vents have generally worked out better than those with vents and their associated closures.

Discomfort. Except for the back-up system, passive designs are usually free running. Excursions out of the comfort zone can be expected unless the design is very carefully thought out and sufficient thermal storage is provided. Summer comfort must receive as much attention as winter comfort. Well designed active systems have fewer problems of this nature because heat storage is usually thermally isolated from the building except when heat is needed. Usually the problem with the passive design can be cured by a more careful design, as discussed above, or, as a second choice, by some active system intervention. However, if an active route is chosen, it must be properly designed and installed.

Many passive systems have superior comfort characteristics, such as an unvented Trombe wall or an underfloor rock bed or block bed, while others have poor comfort characteristics, such as large areas of exposed glass that may be very hot in the day and very cold at night. This subject has been mentioned by many but is far from adequately analyzed. Much more comfortable passive buildings would result if proper account were taken of these issues during the design process.

High Cost. High costs can be attributed to a variety of causes, most of which have been alluded to already, and costs can be reduced by following many of the suggestions that have been made. One factor that has not been discussed is the economy that is realized due to making multiple use of the same component. This is a major consideration in passive solar designs, many of which would not otherwise be cost effective. It is not clear how this principle can be applied to many active systems, but one example would be to combine domestic hot water and space heating storage. It is also usually true that simplifying the system will reduce costs, and care must be taken that multiple use neither compromises performance nor complicates the design.

RECOMMENDATIONS

Improved Communications

The dialog between active and passive solar practitioners can certainly be improved. With better communication should come a better understanding of the advantages and disadvantages of each approach, a willingness to admit problems, and the stimulus to look beyond traditional solutions. This should enable system designers to narrow the gap between active and passive, as described in the discussion above, which should result in better and more acceptable designs and systems. Improved communications should be an important benefit of the recent decision by the American Solar Energy Society to co-locate their annual and passive solar conferences, starting in 1986.

Aesthetics

Both active and passive solar designers should pay more attention to aesthetics. Too many solar buildings are ugly. To achieve widespread acceptance, solar must become more mainstream, more conventional, more desirable. The appeal of solar must be based on more than energy savings to succeed in a world that has settled into a post-crisis attitude about energy. The most obvious avenue is to create a consumer demand for solar, based partly on issues other than energy. The ideal would be achieved when solar and energy-savings characteristics become important secondary considerations in the decision to choose a system or a design approach. To some extent passive solar has been able to achieve this as evidenced by the popularity of sunspaces in the residential marketplace and atria in the commercial building marketplace. But aesthetics must be tempered by a constant determination not to sacrifice performance in the process or the result will be just another passing fad.

Comfort

One way to achieve consumer demand is to be able to deliver a more livable indoor environment both visually and in terms of thermal comfort. This requires stable temperatures, absence of cold drafts, and a comfortable mean radiant environment. The super-insulated buildings described earlier not only use less energy, but they are far more comfortable. Solar energy can aid comfort by adding stable indoor surface temperatures and by improving comfort controls. Visual comfort can be improved by proper use of daylighting.

Integrated Water Heating and Space Heating

The trend toward better buildings provides another opportunity for solar systems. As mentioned previously, the system can be made smaller and the heat distribution more localized, reducing system first cost.

One example of such an integration would be to enlarge a solar domestic hot water heating system to provide some space heat, perhaps doubling the normal size. Solar water heaters are more cost effective than space heaters, given the same system costs, because they are used year around and thus the annual energy savings are greater. Because the fixed cost is already paid by the water heating function, adding collection area to be able to achieve some space heating can be done at a low incremental cost. Increasing the load by adding space heating will increase the heat yield of the larger system because temperatures are reduced, a key factor during cold weather. Distribution of space heat can be at one point in the building, simplifying the system and helping to reduce costs and increase reliability.

Passive system options that integrate water and space heating have also been used successfully; one example is the placement of a water preheat tank or preheat collector in a sunspace. Further development along this path may prove fruitful.

Passive Design Assistance

There are two solutions to the problem of inadequate analysis of passive systems. The first is to form interdisciplinary teams of architects and engineers working together. This has proved to be effective in large architectural firms working on commercial building design where the budget can support an extended design effort, but it is not so effective for smaller buildings. The second solution is to streamline the analysis process. This can best be done by re-design of the computer analysis tools, making them run faster and making them easier to input and more graphic in their output. The output should also be more instructive, that is, more directly informative as to the implications for design decisions. We are just beginning to embark on an era of computer program development for the new generation of powerful small computers. Their success will depend critically on the design of the user/computer interface.

Occupant Participation

It is generally much better to design assuming a minimum participation by the occupant in the operation of the solar energy system. One should also design so that the system can be used by any occupant. Most buildings change owners at least once and a second owner may not be apprised of operation and maintenance requirements. Renters and second owners should not be left to use a system that they cannot understand or cope with. Most people don't expect to need an operating manual for a house, and such instructions are usually misplaced after a while. A passive system should be designed to require virtually no active participation by the user; an active system should be easily understood and repaired by any plumber or electrician.

CONCLUSION

The wide gap between active and passive solar is detrimental in that it tends to obscure opportunities for better design of both types of systems. While a little competition can be healthy, public competition between active and passive solar tends not to be. The real competition is not other solar systems but the challenge offered by a public largely sympathetic to solar energy but not yet sufficiently convinced. Because there is no _a priori_ reason that either an active or passive approach is superior in the design of solar systems, neither group should accept these as artificial boundaries, but work toward the best combination to fit each situation.